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RESUMEN

Aun cuando la pesquería de langosta espinosa estaba supeditada a un simple control regulador desde antes de 1900, no hubo una notable expansión de la pesquería de la langosta espinosa occidental (*Panulirus cygnus*) hasta finales de la década de 1940. Hacia 1963, el nivel del esfuerzo pesquero había excedido al requerido para un rendimiento constante máximo. La introducción de controles administrativos limitados, conjuntamente con la asociación de reglamentación obligatoria, inicialmente tuvieron éxito en una reducción notable del esfuerzo, pero a pesar de limitaciones estrictas de barcos y nasas, el esfuerzo efectivo ha ido en aumento para exceder el nivel de 1963. El resultado es, que mientras el reclutamiento no ha sido adversamente afectado a este nivel de esfuerzo pesquero, el costo para obtener la misma captura con incremento de esfuerzo, resulta innecesariamente alta. La política actual está orientada hacia el abreviar y reducir el esfuerzo pesquero, ambos para mejorar la economía pesquera y fortalecer la confianza en la estabilidad biológica de la pesquería.

El nivel de la investigación realizada refleja la evolución o intensidad de los procedimientos administrativos, y el aumento del valor de la pesquería. La reciente captura anual fue de alrededor de 10 millones de kg, y alcanzaron un valor máximo, para pescadores, de 57 millones de dolares australianos, en que la principal fuente de exportación fue los Estados Unidos. La investigación descriptiva y biológica necesaria para una administración rutinaria ha sido complementada mediante métodos más sofisticados de obtención y análisis de datos, por biólogos federales y estatales, a fin de probar el evalúo de los modelos y facilitar una mejor comprensión de la biología de la langosta espinosa y la relación existente entre reclutamiento y disponibilidad. Se ha hecho un evalúo de la magnitud de la pesca de aficionados, pérdidas debidas a predadores y pérdidas por prácticas pesqueras inadecuadas. La industria pesquera, en base contínua, ha obtenido mejoras en técnicas, barcos y equipos, conocimientos que son necesarios y esenciales para la estandardización del esfuerzo pesquero para uso en los modelos de evalúo.

INTRODUCTION

Historical records refer to western rock lobsters (*Panulirus cygnus* George) as having been caught for sale before the turn of the century (Saville-Kent, 1897). By 1938 the commercial catch was still only 56,000 dozen, and it was not until the 1940's, commencing in 1941 with a wartime demand for food for the armed forces, that rock lobster fishing was begun in earnest. Catches subsequently increased from 270,000 kg by 42 men in 1944-45 to 8.7 million kg by 1,173 men in 1959-60 (Sheard, 1962). In recent years the catch has reached a record 11.4 million kg, valued to fishermen at A$56.7 million. Most of this was exported to North America. The western rock lobster has for many years provided Australia's most valuable fishery. Other Australian commercial rock lobsters, which will not be discussed here, include the southern species *Jasus novaehollandiae* Holthuis which is fished along the southern coastline of Australia, and to a lesser extent various species from more northerly tropical waters. It is not the intention of this review, although it will of necessity draw on a number of previously published works, to provide an

exhaustive description of the western rock lobster, and its fishery. Sources of more detailed information are to be found in the FAO Species Synopsis prepared by Phillips et al (1980).

The Fishery

The western rock lobster is now known to occur along the west coast of Australia from North West Cape (21° 44'S) to Cape Leeuwin (34° 24'S) which mark the boundaries of the currently licensed fishery (Fig. 1). While the early fishery was confined to the vicinity of the two well established centers of population, Fremantle and Geraldton, fishing was expanded northwards and southwards during the late 1940's and in the 1950's, and now there are rock lobster boats operating between Kalbarri and Bunbury, and around the Abrolhos Islands off the coast of Geraldton.

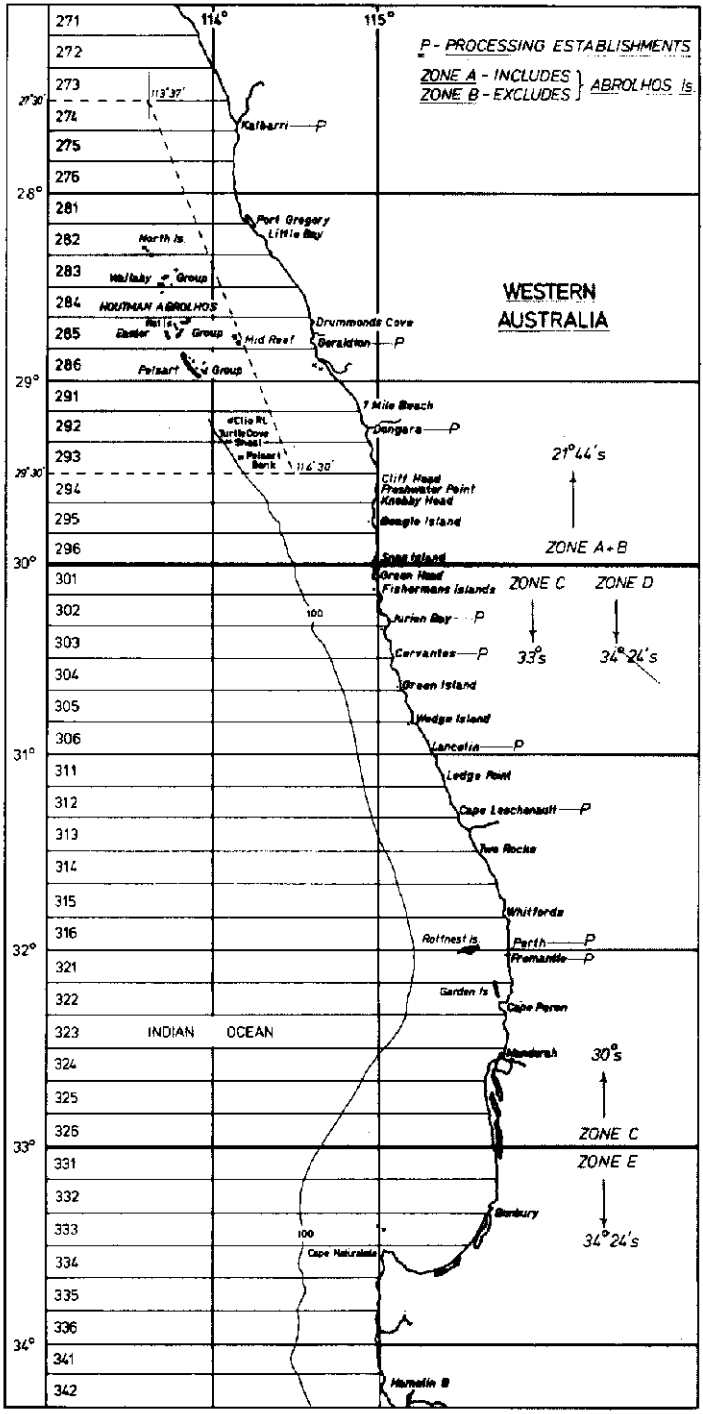
In the early years of the fishery the areas of operation were determined by the size (up to 30 feet) and suitability of the boats to cope with distances and prevailing weather conditions, and the ability of the skippers to locate rock lobster reefs. Pots were pulled by hand. Later, during the 1950's and 1960's, there were significant technological advances including the introduction of echosounders, synthetic ropes, pot winches and pot tippers (Bowen, 1980). Specially designed boats, many having high speed planing hulls with speeds up to 25 kn, ample deck space for transporting gear and transferring pots on a daily basis became a feature of the early 1970's. Currently there are 801 boats in the fishery of which 1% are less than 6 m, 82% 6-12 m and 17% larger than 12 m. In the early years there were 45 freezer boats, but all except 7 of these have been phased out under Government policy, the remainder all being day boats. Pots of traditional design are still used — stick (or cane) and wire, "beehive" pots in waters of all depths, and wooden "batten" pots originally in shallow protected waters but more recently in all depths. Pots are set individually, each with polystyrene floats one of which must be marked with the boat license number. Weather permitting, pots are lifted, baited and reset each morning. A wide variety of baits are used (Morgan and Barker, 1979) the most popular being the heads of Australian "salmon" (*Arripis trutta*) and other fish, used together with bullock hocks and hides. From the 1977-78 season, the coastal fishing season has been shortened to the period 15 November to 30 June, with the Abrolhos fishery from 15 March to 30 June. For a number of years prior to this both seasons were closed on 14 August. There is a recreational fishery for rock lobsters which accounts for about 2% of the professional catch.

There are rock lobster processing establishments at eight coastal locations, where up to 95% of the catch is packed as individually wrapped uncooked "tails" for the U.S. market, while small quantities are cooked whole for local and European markets. More detailed accounts of the fishery between 1944-1961 have been given by Sheard (1962), and of recent years by Bowen (1980), with published annual reports by Morgan and Barker (e.g. 1979).

Sources of Data

Rock Lobster Production Monthly Return. It is mandatory for licensed rock lobster fishermen to provide details of weights landed by area (1° statistical blocks),

Figure 1. The coastline of Western Australia, showing rock lobster licensed fishing zones, locations of processing establishments, and area codes (271-342) for fisherman's research log books. →


P - PROCESSING ESTABLISHMENTS
ZONE A - INCLUDES } ABROLHOS Is.
ZONE B - EXCLUDES }
WESTERN AUSTRALIA
INDIAN OCEAN
ZONE A+B
ZONE C
ZONE D
ZONE E
21°44's
33°s
34°24's
30°s
114°
115°
113°37'
116°30'
27°30'
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Kalbarri
Port Gregory
Little Bay
North Is.
Wallaby Group
HOUTMAN ABROLHOS
Easter Group
Mid Reef
Pelsart Group
Drummonds Cove
Geraldton
7 Mile Beach
Dongara
Clie Rk
Turtle Dove Shoal
Pelsart Bank
Cliff Head
Freshwater Point
Knobby Head
Beagle Island
Green Island
Fishermans Islands
Jurien Bay
Cervantes
Green Island
Hedge Island
Lancelin
Ledge Point
Cape Leschenault
Two Rocks
Whitfords
Rottnest Is.
Perth
Fremantle
Garden Is
Cape Peron
Mandurah
Bunbury
Cape Naturaliste
Hamelin B
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average number of pots pulled per day, and number of fishing days for each depth (< or > 82m). Records are collected by the Western Australian Department of Fisheries and Wildlife under the Fisheries Act 1905 and processed by the Australian Bureau of Statistics.

Rock Lobster Processors' Monthly Return. It is mandatory for rock lobster processors to provide details of their suppliers (home anchorage, registered boat number, live weight supplied to them) and sales (numbers of boxes, identified in four sizes of box, of processed, fresh frozen, rock lobster tails in seven grade categories by weight; together with weight of rock lobsters sold ungraded cooked whole). Figures for rock lobsters held in cold storage are published at regular intervals.

Index of Annual Landings. Three key processing establishments (at Geraldton, Jurien Bay and Fremantle) provide, for research purposes, monthly figures of catches received. These can be compared with data from the same sources in previous years to give a forecast of the season's success, ahead of published data.

Research Log Sheets. Commenced in 1965, with voluntary completion by 20-25% of the total 801 rock lobster boats, giving daily records of fishing latitude within a 10-mile transect (Fig. 1), number of pots used and estimated weight of catch in four depth categories (0-10, 10-20, 20-30, over 30 fm), number of days between pulls (soak time), and in latter years numbers of berried females and numbers of octopus taken, together with remarks on weather, tide, currents, moon phase, etc.

Factory Measurements. Commenced in 1965 to provide measurements of rock lobsters caught in the Geraldton/Dongara, Jurien Bay, and Lancelin/Fremantle areas. Discontinued in 1967 because the information proved to be of less value than expected and was later replaced by monitoring at sea (see below).

Monitoring Commercial Vessels at Sea. Commenced in 1971. Two Technical Officers measure samples each month of the fishing season, each sample to be of no less than 400 individuals, from each of four depth categories used on the log sheets mentioned previously, and from four ports (Dongara, Jurien Bay, Lancelin and Fremantle), recording carapace length, sex, breeding state, etc. Results are included in reports of the rock lobster fishery published annually (Morgan and Barker, 1979).

Economic Studies. Conducted periodically and results published by the Commonwealth Department of Primary Industry (1974 and 1978). Studies are designed to provide data on the economics of fishing in the various zones of the fishery, by different sizes and designs of vessel, and the economic consequences of various management measures.

Research Programs. These are detailed in a later section.

Information from the Fishing Industry. In addition to the contributions made by the fishing industry to the data requirements listed above there is a continual verbal and written dialogue between the fishing industry and the Department of Fisheries and Wildlife and its Research and Inspection Branches, the Commonwealth Department of Primary Industry and the CSIRO (Commonwealth Scientific and Industrial Research Organization — Division of Fisheries and Oceanography, now separated into two Divisions), and notably through the Rock Lobster Industry Advisory Committee which includes strong industry representation (see below).

Biology and Life History

The following summary is based on research over the years by a number of organizations referred to in a later section, and detailed by Phillips et al (1980).

Mating takes place during Winter/early Spring (May - June) when the male deposits a sperm packet ("tar spot") on the underside of the female carapace. Eggs (100,000-700,000 depending on female size) are laid in spring/early summer (September-December) fertilized as the female punctures the sperm packet, and attached to elongated setae on the endopodites of the pleopods. Eggs hatch after 3 or more weeks depending on water temperature, into phyllosoma larvae which, during 10 months at large in the Indian Ocean, develop through nine larval stages before settling during September-January as puerulus on inshore reefs. They remain there as juvenile stages until about 4-5 years old, when, each year during November-December, recently molted, lightly colored, immature animals commence an offshore migration. Of these, rock lobsters which have achieved the legal commercial size of 76mm carapace length contribute to the "whites" fishery. The survivors darken in color and become part of the main "reds" fishery. Larger animals are found in deeper waters where they are fished to 100 fathoms. Sexual maturity begins at 5-6 years at a size which varies regionally in the fishery.

ADMINISTRATION OF THE FISHERY AND RESEARCH PROGRAMS

Australia is a federation and under constitutional arrangements, since the rock lobster fishery lies both inside and outside of the 3 mile sea boundary of State territorial responsibility, management is shared by the State Department of Fisheries and Wildlife, and the Fisheries Division of the Commonwealth Department of Primary Industry. Rock lobster fishermen therefore require both State and Commonwealth licenses. Day to day management, including issue and transfer of licenses, patrolling and inspection, is the responsibility of the State Department of Fisheries and Wildlife. Biological research is the responsibility of the State Department and the Commonwealth Scientific and Industrial Research Organization. Economic research is undertaken by the Fisheries Division of the Department of Primary Industry, which organization has responsibility for export quality control. Biological and economic research has also been undertaken at the Western Australian Museum and by the University and other tertiary education institutions.

The need for coordinating research by such an array of organizations was recognized by the establishment in 1961 of the Western Fisheries Research Committee, membership of which includes the State Director of Fisheries and Wildlife (Chairman), Chief of the Division of Fisheries and Oceanography (CSIRO), Head of the Fisheries Division of the Department of Primary Industry, Professor of Zoology, University of Western Australia, a senior representative of the Department of Fisheries of South Australia, and the Research Coordinator. The author has held the latter position since 1972.

At the industry/government level the Rock Lobster Industry Advisory Committee provides advice to the management authority on matters relating to the industry, and includes among its membership three professional and one amateur rock lobster fishermen and two rock lobster processors, in addition to government members and scientific advisers. This Committee provides advice on proposed

changes to management rules and initiates discussion with individuals and fishing industry groups.

The cost of administration, inspection and research to the State management authority specifically relating to rock lobsters amounted to A$1.35 million in 1979-80, which represented about 2.5% of the gross local value of the catch. Of this, 18% was for administration, 61% for inspection and 21% for research. Only a small part of this was covered by revenue from the industry which amounted to $285,000. This was mostly made up of limited entry license fees, at $3.50 per pot for 76,000 pots (increased to $4.30 for the 1980-81 season), which are paid into a trust fund for fisheries research, together with a small amount for fishing licenses ($14 each) and boat license fees ($10-$20 according to boat size). The budget for rock lobster fishery inspection amounts to about 60% of the total fisheries inspection expenditure for the State. Additional funds for special research projects may be received on application to the Commonwealth Fishing Industry Research Committee. These funds have been used for setting up the fishery monitoring program, and for studies of octopus predation, the amateur fishery and the fishery-induced mortality of undersize rock lobsters, usually on a 3-year basis.

Management Measures

Limited Entry. In March 1963, the maximum number of rock lobster boats was fixed. At that date there were 829 boats allowed — the current number is 801. The number of pots allowed was limited to three per foot of boat length with a maximum of 200 pots. In 1965, in order to curb the tendency towards larger vessels eligible for more pots, firstly increases in pots per vessel were prohibited and then, with minor exceptions relating to safety, increases in boat length. Modified regulations introduced in 1979 allow greater flexibility in replacement boat size and in transfer of pots between vessels, which within the strict criterion of restraining fishing effort, will allow greater financial flexibility for individual fishermen. Licenses are transferable and therefore attract financial transfer benefits to fishermen (Bowen, 1980).

Limited Areas. Boats fishing Zones A and B (Fig. 1) may not fish south of 30° S. Zone B licenses permit fishing only in the coastal area. Zone A licenses allow fishing along the coast from November 15 to March 14, and the Abrolhos Islands from March 15 to June 30. Zone C licenses may fish between latitudes 30-33°S, Zone D from 30° to 34° 24'S and Zone E from 33° to 34° 24'S (Fig. 1), all from November 15 to June 30.

Closed Seasons. Coastal fishery: Closed outside November 15 to June 30. Abrolhos Islands: Closed outside March 15 to June 30.

The seasons were shortened by 6 weeks (July 1 to August 14) from 1977. Various modifications of a closed season have been in force during the history of the fishery, commencing in 1897.

Minimum Legal Size. 76mm carapace length, 140 g tail weight. Size controls date from 1897 and reflected size at first maturity and market requirement.

Berried Females. Prohibited since 1899.

Escape Gaps in Pots. Each pot must include a rectangular escape gap no less than 54 mm wide (high) and 305 mm long, to permit the escape of sub-legal sized rock

lobsters. From 1966 (2 in), amended to 2-1/8 in (=54 mm) in 1972.

Design and Size of Pots. A pot may have only one entrance (from 1973), which may not be at the side (from 1981), and must not exceed 1 m length or diameter (from 1981). Measure introduced to standardize and control the unit of fishing effort.

Amateur Fishermen. Each individual must be licensed and may use no more than two pots, with a maximum take of eight rock lobsters in any one day.

Capture by Diving. Prohibited at the Abrolhos Islands. Spearfishing is prohibited throughout the fishery.

Freezer Boats. Freezer boats are subject to several special regulations.

Objectives of Management

During the early 1960's the Western Australian Government was faced with a common property resource which was being fished increasingly by professional, and fractionally by amateur, rock lobster fishermen. The rapid expansion of a fishery with unrestricted access had led to levels of fishing effort which appeared to have exceeded that required for maximum sustainable yield (MSY) and therefore well in excess of those for maximum economic yield. In introducing management by limiting entry to units already fishing or with some prior claim to do so, the objective by inference was to maintain employment at the existing level. Restriction of the fishing capacity of the fleet by permitting a reduced number of pots, i.e. *pro rata* per length of vessel, represented an attempt at restraining fishing effort towards levels required for maximum sustainable yield. However, as concluded by the ACMRR Working Party (1980), management based on a biological objective such as MSY will inevitably result in over-capacity in the fishery and dissipation of the potential economic benefits which might be achieved if "optimization" involved socio-economic objectives with biological constraints. A tendency towards over-capacity is perhaps even more likely where the optimum has already been exceeded previously and, as Morgan (1980a) has reported, effective fishing effort continued to increase even within the strict limitation of number of boats and pots. Moreover once the precedent has been established for an employment level in excess of that required for an alternative objective it proves to be difficult to withdraw it, both politically and socially. The result is that, while recruitment seems not to have been adversely affected, the cost of achieving the same catch with increasing effort is needlessly high. Current policy is directed towards means of curtailing and reducing fishing effort, both to improve the economics of fishing and to strengthen confidence in the biological stability of the fishery. While a reduction in the number of boats, for example by a "buy-back" scheme, is one of the most attractive options, this is likely to be a prohibitively expensive exercise at current values. Meanwhile the consequences of a number of conservation measures, including shortening of the fishing season from 1977, will be carefully monitored before considering whether further constraints, such as reduction in the number of pots in the fishery, are appropriate. To date the management alternative of fixed quota levels has not been favored, on the grounds of dampening of incentive, problems of policing and difficulty of forecasting quota levels, notwithstanding Clark's (1980) view that allocated catch quotas appear to offer the best alternative, in terms of feasibility and efficiency.

Evolution of Research Programs

The intensity and direction of rock lobster research have evolved in parallel with the phase of development and increasing value of the fishery, i.e. developing, regulated, fully exploited and fully controlled.

The Developing Fishery. Required mainly descriptive and technological research, i.e. the search for grounds with fishable densities, the search for the most effective catching techniques (size and design of pots, bait containers, pot tippers and haulers, choice of bait, timing and duration of setting gear, choice of ground and season, boat design etc.) and the search for markets. In the western rock lobster fishery, the fishing industry itself has been largely responsible for such technological innovation.

The Regulated Fishery. Required biological research to determine appropriate regulations, as follows:

MINIMUM LEGAL SIZE — size/weight/age composition of the stock, growth rates, mortality rates, size/age at first maturity, migrations.

CLOSED SEASON — to protect spawning stock (or young), (to maintain market quality) and to reduce fishing effort: spawning season, growth rates, longevity, rate of exploitation, seasonal changes in quality.

BERRIED FEMALES — fecundity, definition of unit stock, stock/recruitment relationship, catch losses due to controls.

GEAR RESTRICTIONS — escape gap size, pot size and design, boat size: size composition of the stock, size composition of the catch with different gears, growth and mortality rates.

CLOSED AREAS — to protect nursery areas (or spawning stock) or to reduce overall effort: migrations, spawning season and distribution of spawners, distribution of nursery areas, growth and mortality rates of juveniles.

The Fully-exploited Fishery. Requires assessment research, quantification of parameters, standardization of fishing effort for testing and designing models for yield assessment, growth models, stock-recruitment relationships etc, based on data collection from the developing and the regulated fisheries above.

The Fully-controlled Fishery. Involves updating and extension of data collection; monitoring of catch, fishing effort, recruitment, breeding index and biological characteristics of the fishery; quantifying other outputs from the fishery, for example, by amateur fishermen, predators; and reducing wastage due to predators and poor handling practices.

HISTORY OF ROCK LOBSTER RESEARCH IN WESTERN AUSTRALIA

[Chronology partly by courtesy of B.F. Phillips (unpublished document)].

1946

K. Sheard (CSIRO, then CSIR) collected and published (Sheard, 1962) catch, fishing effort and catch data.

1953

R.W. George (then with CSIRO, now with W.A. Museum) commenced biological studies, larval studies and taxonomic studies.

1961

A new phase of research commenced with the formation of the Western Fisheries Research Committee (WFRC) which approved a joint research project on the exploited phase (by W.A. Department of Fisheries and Fauna) and the recruitment phase (by CSIRO Division of Fisheries and Oceanography). Studies of the exploited phase initiated by B.K. Bowen included growth rates, size composition of the catch, catch rates and size at maturity.

1963

R.G. Chittleborough (CSIRO) commenced studies of juveniles, and took over larval studies from George. Bowen (1963) published the results of his research on escape gaps, following which a 2 in escape-gap was introduced in 1966.

1964

Bowen and Chittleborough (1966) reported the first attempt at stock assessment, and recommended urgent research on growth, mortality and migration with more detailed catch records. This led to the introduction of fisherman's research log books, a measuring program in four major fishing areas, and tagging programs in the coastal and Abrolhos fisheries. CSIRO officers concentrated on the larvae, including their dispersal and return and the influence on them of the water circulation of the Indian Ocean, together with aquarium testing of tags, aquarium observations on growth, and studies of juvenile densities on inshore reefs.

1967

B.F. Phillips (CSIRO) commenced research on the last larval (puerulus) stage and the early settled stages. WFRC stressed the need for an oceanographic and plankton study of the eastern part of the Indian Ocean, one aim being to use larval densities (i) as an index of breeding stock, and (ii) to provide a basis for forecasting future catches.

1968-71

G.R. Morgan (State) commenced a study of factors affecting catchability, involving a series of monthly mark-recapture experiments over several years.

In 1969 W. Dall (CSIRO) commenced a physiological study of the intrinsic factors controlling growth and molting. D.A. Ritz (CSIRO) reported (1972a and b) the results of his larval program which was discontinued, principally because of the unsuitability of the vessel to work in prevailing weather conditions. Plans were made for a much larger larval program to measure the size of the rock lobster stock. Chittleborough (1970) reported his studies of juvenile densities, growth and mortalities, and commenced an examination of the possible use of artificial shelters as increased habitat.

Phillips (1972) described a successful puerulus collector which would be used to assess the numbers of puerulus returning to the coast. A State program was commenced in 1971 to monitor commercial vessels at sea by sampling from four ports in four depth categories for size composition, sex, molting and breeding, to provide a basis for observing any long term trends in the fishery.

1972

Morgan (1972) reported on the fecundity of the western rock lobster. Discussions were held on a systems analysis approach to identifying key areas for research.

1973-4

The CSIRO larval program was implemented using a charter vessel. J.P.R. Hindley (CSIRO) commenced a study of the behavior, particularly feeding, of juveniles. L.M. Joll (State) commenced a 3-year program on predation of rock lobster by octopus. Chittleborough (1974a-d) reported on prospects for pond rearing of rock lobsters, on tag design, and on home range, homing and dominance in juveniles. Morgan (1974a and b) described the results of his studies on catchability and density estimation.

1975

Morgan and Barker (1975) published the first of a series of annual reports on the rock lobster fishery, including monitoring data. Dall terminated his physiological studies and published a series of papers including two (1975a and b) on indices of nutritional state. CSIRO concluded that the distribution of early phyllosoma larvae was too patchy to give a precise enough measurement of overall density to measure changes in the size of the breeding stock. Instead, new emphasis was given to a study of the mechanism of patchy distribution, and to relating factors governing larval movement and distribution to variation in abundance of returning puerulus, and their dependence on oceanographic factors. Chittleborough (1975) and Chittleborough and Phillips (1975) described factors affecting growth and survival of juveniles, and fluctuations in year class strength and recruitment.

1976

Chittleborough (1976) completed his study of breeding under natural and controlled conditions. Studies of physical oceanography (CSIRO) were intensified including satellite-tracked buoys to follow currents. A State study of the amateur fishery was commenced by P. Norton. Hindley (CSIRO) reported on his behavior studies. Phillips and Campbell (CSIRO) concluded from their systems analysis study that the catch of the coastal "whites" fishery and associated effort data provide the best measure of recruitment.

1977

The 4-year CSIRO program on larvae and water circulation was completed. A 3-year grant-aided study was commenced by L.M. Joll (now CSIRO) on the food and feeding of juveniles. R.S. Brown (State) commenced a 3-year grant-aided study of the fishery-induced mortality of undersize rock lobsters, intended to review and improve handling practices. The completed study of octopus predation (Joll, 1977) estimated losses of rock lobsters in pots to be around $400,000.

1978

The CSIRO rock lobster program was revised to a coastal ecology program (to be led by W.J. Wiebe) of which rock lobster ecology became one segment. Morgan (State) reported the results of yield assessment modelling. Norton (in prep.) reported that catches by amateurs amounted to no more than 2% of the professional catch. A study of the feasibility of an octopus fishery, with one objective being to reduce predation of rock lobsters in pots, was commenced under an Australia/Japan agreement.

1979

The study on food and feeding of juveniles (Joll, 1977) was completed.

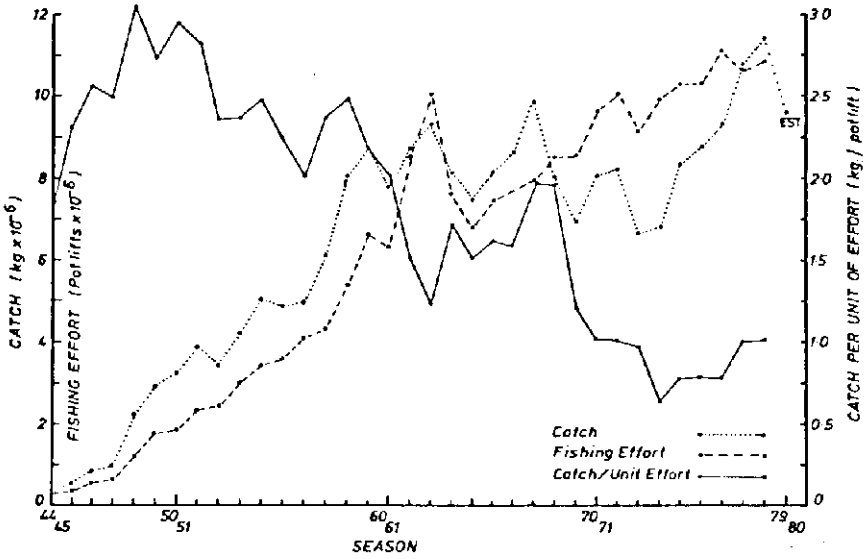

Figure 2. Annual catch, nominal (uncorrected) fishing effort and catch per unit of effort from the Western Australian rock lobster fishery 1944/45-1978/79 (1979/80 catch estimated).

1980

CSIRO rock lobster ecology programs are concentrated on home ranges, diurnal activity rhythms, daily food intake and assimilation in areas of different population density and food quality, density dependent survival and identification of important predators. Morgan, Phillips and Joll (in prep.) reported a synthesis of data on puerulus settlement, juvenile densities and eventual catch (stock/recruitment relationships). The study of the fishery-induced mortality of undersize rock lobsters (Brown) indicates significant losses of rock lobsters due to handling.

ASSESSMENT OF THE FISHERY

Figure 2 gives the history of annual catch, fishing effort (pot lifts) and catch per pot lift from 1944-45 to 1978-79.

The first stock assessment of the western rock lobster was published by Bowen and Chittleborough (1966). The authors concluded that the fishable stock, originally of approximately 140 million lb had declined to some 35 million lb by 1963. Exploitation rate had risen as fishing effort was increased but then levelled off, generally at above 60%, as a result of which the fishable stock available on the grounds at the opening of the season had become largely dependent on recruitment by growth of juveniles. They believed that recruitment had been diminishing from year to year because of mortality of undersized, pre-recruits handled during fishing, and recommended the provision of escape gaps in all pots. (2-in escape gaps became mandatory in 1966, with an increase to 2-1/8 in (=54mm) in 1972). Bowen and Chittleborough suggested that a sustainable level of catch might be 16 ± 2 million lb

(7.3 ± 0.9 million kg) annually if recruitment could be stabilized, while some further restriction of fishing effort might be necessary.

Morgan (1980b) applied both dynamic pool and surplus yield assessment models to data from the fishery up to the 1975-6 season. He found limitations in fitting dynamic pool models (Beverton and Holt, 1957; Ricker, 1958) which, although they have the considerable advantage that they can be used to forecast the effects on the catch of changes in minimum legal size, suffer, when applied to the western rock lobster, from a lack of precision which would limit their usefulness as a base on which to make management decisions. This lack of precision results from the difficulties, common among crustacea, of making precise estimates for growth and mortality parameters. For the time being therefore, Morgan placed greater emphasis on surplus yield models (Schaefer, 1957) and subsequent modifications (Pella and Tomlinson, 1969; Marchesseault et al., 1976), while concluding that because dynamic pool models are more realistic in their description of a fishery, it is important that their inherent problems when used in crustacean fisheries be overcome so that reliance is not made solely on the simple surplus yield models.

Figure 3b is based partly on Morgan's (1979a and b) presentation of catch and effective fishing effort, together with his fitted Schaefer curve covering the years up to and including 1975-76. Effective fishing effort takes into account temporal changes in vulnerability and the spatial distribution of pot lifts relative to rock lobster distribution (Morgan, 1979a and 1980a) and involves the adjustment of monthly pot lift data in various areas of the fishery by the relative vulnerability to capture of the rock lobsters each month and using the method of Gulland (1969). Three additional data points have been added for the seasons 1976-7 to 1978-9 and the Schaefer curve refitted, not including the forecast figure for 1979-80. It can be seen that the 2 years, 1977-8 and 1978-9, were maximal in terms of both catch and effort, and the inclusion of the three additional points has had the effect of extending the curve to provide slightly higher estimates of MSY (9.3 million kg) and optimum effort (7.2 million pot lifts) than obtained by Morgan (8.6 million kg and 5.9 million pot lifts). The difference between the two results represents not only the additional data points, but also a different fitting technique,that is the equilibrium approximation of Fox (1975) rather than Schaefer's iterative procedure. However, the application of the equilibrium approximation to Morgan's data provided a result very little different (8.7 million kg and 5.7 million pot lifts) from his. It should be noted that despite the fact that the seasons were shortened by 6 weeks in 1977-78 and 1978-79 (also 1979-80) there was a substantial increase in effective effort, which was due to a redistribution of effort to periods of greater catch rate and vulnerability.

Actual (nominal) effort figures have been given for comparison in Figure 3c for which a fitted Schaefer curve, noting that this may be biassed through the use of a poor effort measure, gave a similar maximum catch of 8.9 million kg. However, the optimum fishing effort (9.9 million nominal pot lifts which is approximately 8.5 million effective pot lifts based on 1978-79 figures) was considerably in excess of that obtained using effective effort. It can be seen that shortening of the season by 6 weeks achieved a reduction in actual pot lifts of 5% but much of this was compensated for in following years.

Figure 4 gives the relationships between catch and nominal effort for six selected areas of the fishery. While again these may be biassed through changing efficiency of

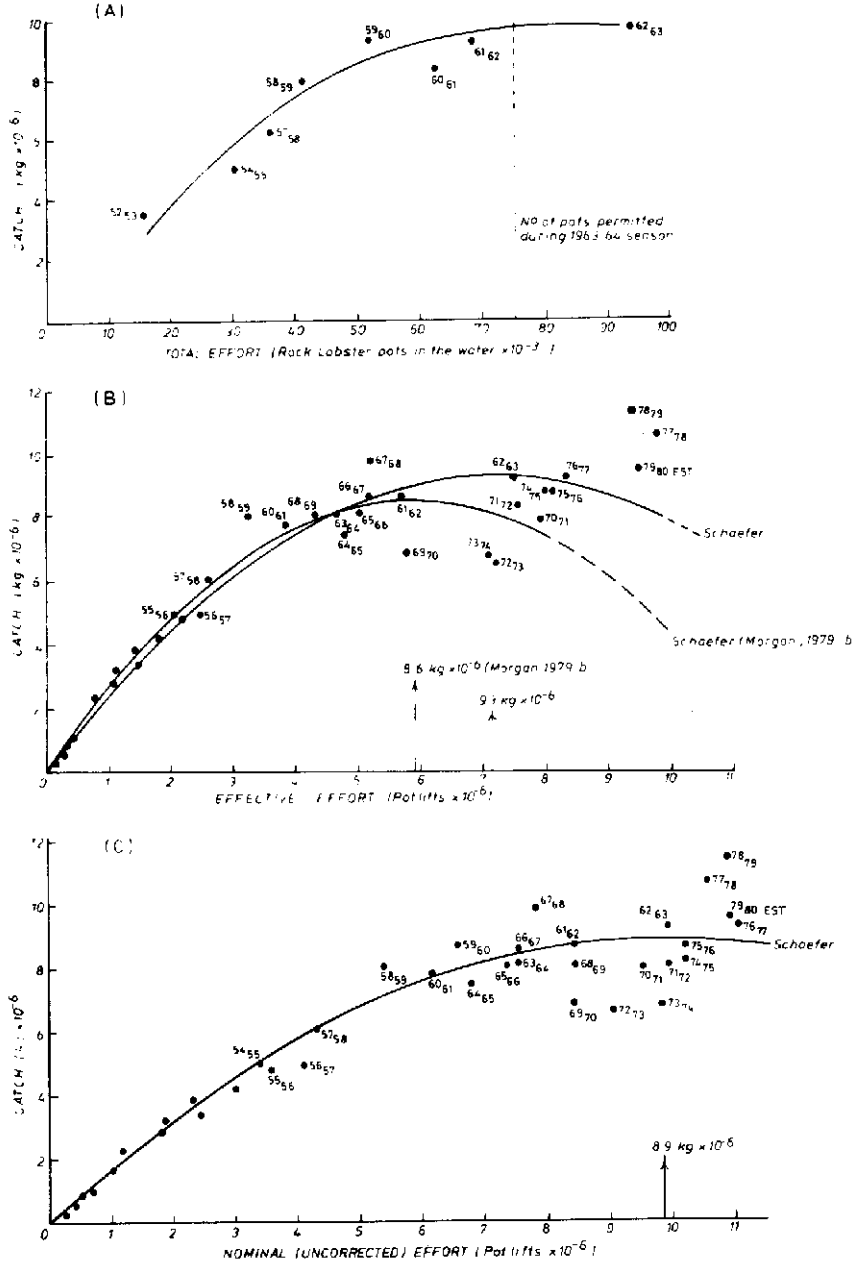

Figure 3. (A) Line, fitted by eye, relating annual catches and total (uncorrected) fishing effort for 8 years from the western rock lobster fishery (after Bowen, 1971); (B) Annual catches related to effective effort to compare the fitted Schaefer curve for the years up to 1975/76 (from Morgan, 1979b) with the curve for years up to 1978/79; (C) Annual catches related by a Schaefer curve to nominal (uncorrected) effort for the years up to 1978/79.

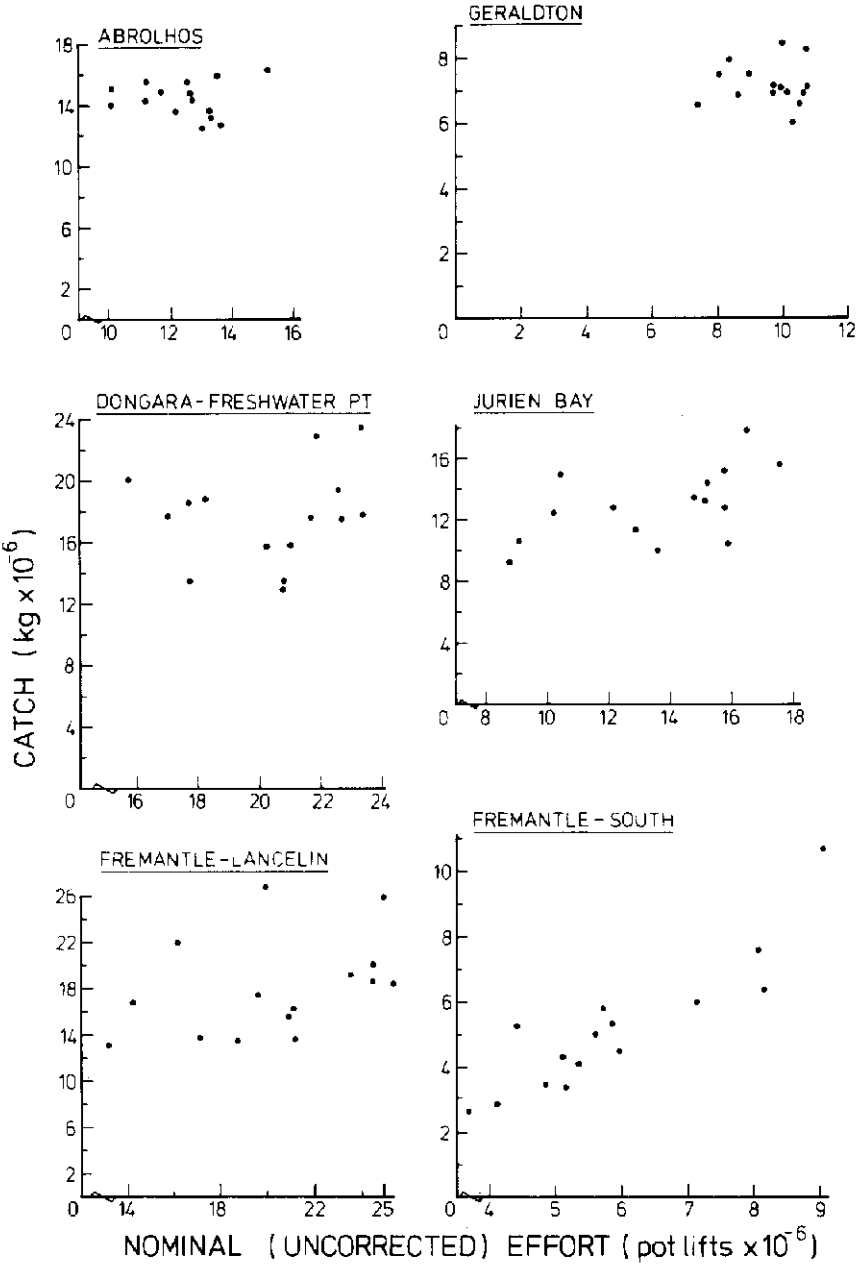

Figure 4. Annual catches, 1964/65 to 1978/79, related to nominal (uncorrected) effort, from six selected areas (reference Figure 1) of the western rock lobster fishery.

nominal effort the graphs serve to indicate a difference between northern, where catches on average show no increase with increasing effort, and southern areas which do. In 1979-80, for which only estimated figures are available, catches at Geraldton were reduced by 21% compared with 8% at Fremantle and 16% as an average for the fishery.

Figure 3a shows the history of the fishery to 1962-63 when, with the creation of a limited entry fishery and reduction in the number of pots, the nominal effort was reduced by about 25% (Fig. 3c). Both Figures 3b and 3c trace the great increase in fishing effort since that date (Morgan, 1980a), while the further increase in effort which occurred despite shortening of the season (see above) indicates that the potential for increase had still not been eliminated.

Morgan (1979b) also used GENPROD, PRODFIT and Marchesseault et al's (1976) delayed recruitment model to obtain results not dissimilar to those from the Schaefer model. The range of estimates of MSY from these models (8.0-8.6 million kg) is given in Figure 5 which shows that the mean annual catch over 15 years lies within the range of these estimates. While an asymptotic curve (e.g. PRODFIT with m = o) would appear to represent the data as well (and certainly would give a more optimistic interpretation) as those shown in Figure 3, Morgan obtained from this a poorer fit to the data.

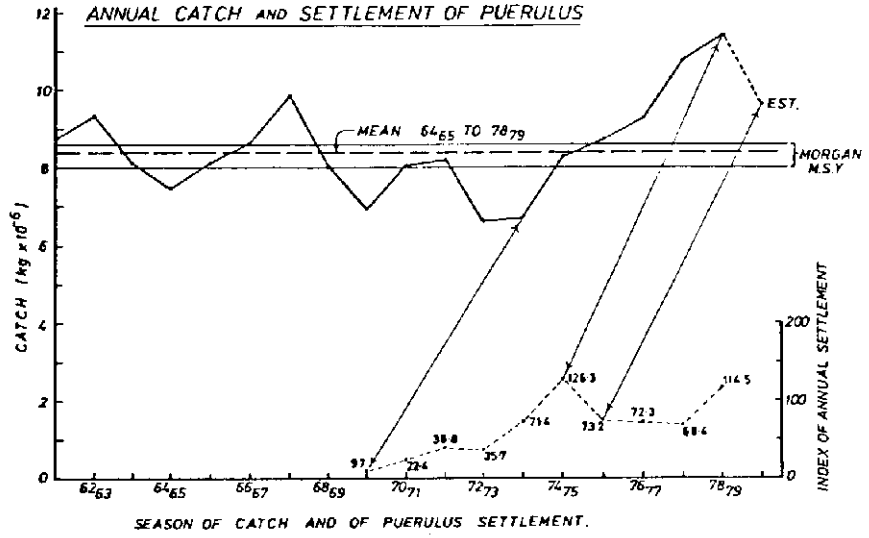

Figure 5. Annual catches from the western rock lobster fishery, showing the mean annual catch (8.48 m kg) during the years 1964/65 to 1978/79, the range (8.0-8.6 m kg) of estimates of MSY obtained by Morgan (1979b) using Schaefer, GENPROD, PRODFIT and delayed recruitment models, and the relationship between indices of puerulus settlement (from Chittleborough and Phillips, 1975, and Phillips, pers. comm.) and total catches from the fishery 4 years later.

Information Required for Standardising Units of Fishing Effort (to give effective effort, measured as "number of pot lifts")

Clearly when attempting to standardise data on fishing effort so as to allow meaningful comparisons between years in an assessment model there are ideally many factors to take into consideration. Those appropriate to the western rock lobster fishery have been summarized in this section. All likely causes of bias will need to be considered when evaluating the reliability of assessment curves for management purposes.

Adjustments Made. Area fished; Seasonal vulnerability as affected by temperature, molting, salinity (Morgan, 1979a); Length of season — season shortened from 1977.

Adjustments Assumed Not Required (nevertheless under review). Soak time (Morgan (1979a) concluded that catch is unchanged with soak time); Pot design (Morgan concluded that catches differ little between designs used); Catches by amateur fishermen (Norton, in prep.) concluded that amateur catches amounted to about 2% of professional catches, but they must inevitably increase; Effect of moon phase (assumed cancelled out by adding over the months); and Effect of weather (assumed to be a random variable).

Adjustments Unnecessary Because Gear Standardized. Number of pot entrances: multinecked pots are more efficient, but legally must not exceed one (from 1973), entrance not to be at side (from 15 Nov. 1981); Size of pot: large pots are more efficient at times of high density but must not exceed 1 m from 15 Nov. 1981; Size of boat: efficiency is a function of boat size and boat replacement policy limits increases in boat size.

Quantitative Basis for Adjustment not Available. Increased operator efficiency — underestimates effort; Improved technology and gear — underestimates effort; Bait fashions (choice and quantity) — direction of bias unknown; Unreported (illegal) pots — underestimates effort; Competition between gear units — direction of bias unknown; Pot saturation — underestimates catch; Competition between bait with natural food — direction of bias unknown; Variable abundance of predators, e.g. octopus — direction of bias unknown.

Unquantifiable Long-term Changes Affecting Catch Rates. Quality of reporting — may improve with experience and understanding by operators; Under reporting of catches — underestimates the catch, this reflects (unwarranted) suspicion of use of records for tax purposes; Changes in escape gap size — the direction of bias unknown; Improvements in surveillance — to reduce illegal fishing which causes underestimation of effort and catch, landing of undersize lobster which causes underestimation of catch, and retention of spawners, direction of bias unknown.

Recruitment

Figure 5 shows annual indices of puerulus settlement combined from three coastal stations and the Abrolhos Islands, from Chittleborough and Phillips (1975), with additional data points from Phillips (pers. comm.). This suggests a relationship between the level of puerulus settlement and the total catch 4 years later. The latter would contain many year classes but would include a significant contribution (of the order of 30-40%) from the "whites" fishery, which is composed mainly of individuals

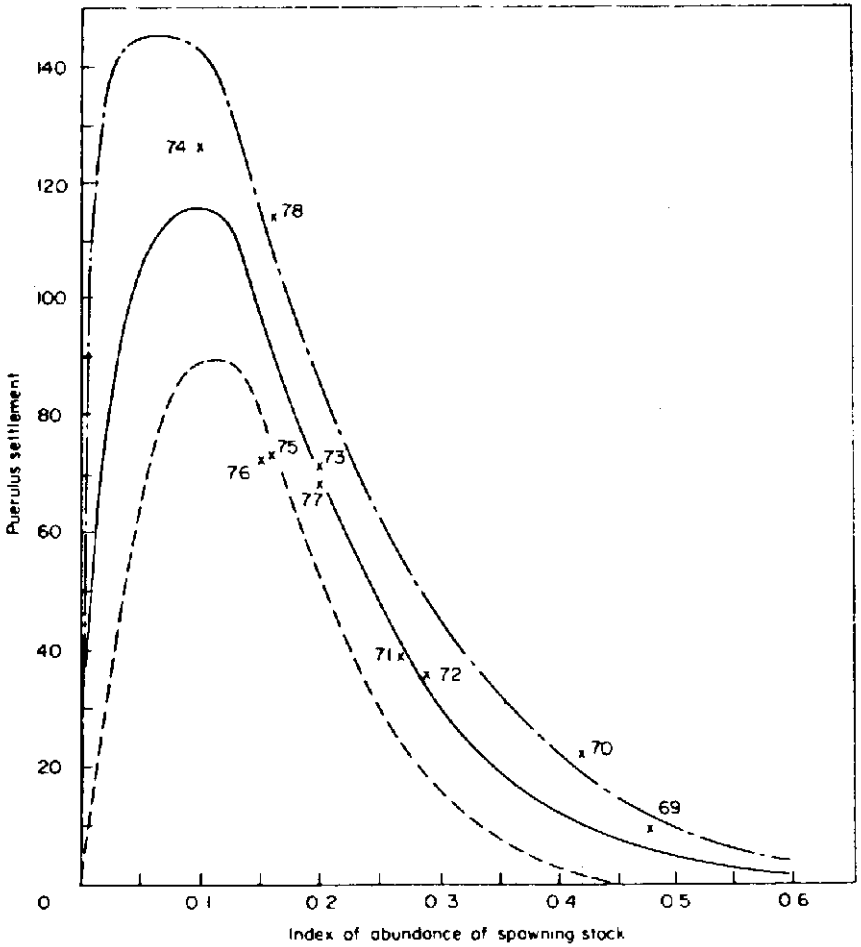

Figure 6. The relationship between the abundance of the spawning stock of *Panulirus cygnus* and the subsequent settlement of puerulus larvae for the years 1969-78, together with the 95% confidence intervals (from Morgan, 1980b).

of 5 years of age, i.e. puerulus of 4 years previously. Chittleborough and Phillips (1975) concluded that a prediction of the relative success of the "whites" fishery can only be made following the appearance of a particularly poor year-class, e.g. the poor catches of 1972-3 and 1973-4 following low puerulus settlement in 1969-70. The predictive value of heavy puerulus settlement is weakened because of factors limiting survival and growth of juveniles, predominantly the limited availability of food on the coastal reefs.

Morgan, Phillips and Joll (in prep.) are making a careful study of the quantitative relationships between various phases of the rock lobster's life history for predictive purposes, one of the most important relationships being that between an index of spawning stock and the index of puerulus settlement cited above. Figure 6, which is

taken from Morgan (1980b) and is based on Morgan's spawning index figures and Phillips' puerulus settlement data, shows that Ricker's (1958) stock-recruitment relationship gives a good fit to the data and clearly indicates a reduction in spawning stock from 1968 onwards accompanied by increasing settlement of puerulus about 1 year later (1969 on).

Effectiveness of Management Measures

Morgan (1977) concluded that the present and long-established *minimum legal size* is somewhat below that which would produce maximum yield per recruit at the present fishing intensity. However the expected increase in yield which would result from a larger minimum size would be small and would be offset by significant expected decreases in total landings in the short term, i.e. pending more precise estimates of the parameters involved in calculation the minimum legal size must be regarded to be at least moderately effective in present circumstances. However any reduction in fishing mortality achieved by current management policy should increase the effectiveness of the present minimum legal size.

The *closed season* has played an important role in limiting annual fishing effort though there has remained considerable potential for increase in the level of effective effort within the permitted season, with, according to Morgan (1980a and b) a further potential for increase beyond the current 9.5 million pot lifts to 13.7 million. Clearly a closed season alone is an inadequate means of constraining effort.

The prohibited capture of *berried females*, while of doubtful value as a conservation measure during the developing phases of the fishery, needs to be viewed more seriously as the spawning index becomes reduced by heavy exploitation to the lower levels shown in Figure 6, below which the model suggests that recruitment could become seriously reduced. In addition, the *closed season* affords protection to coastal stocks during mating, while spawners at the Abrolhos Islands are left undisturbed during the extended closed season (= seasonally *closed area*) there. One important reason for extending the Abrolhos closure was to avoid high handling and transport mortalities of freshly molted rock lobsters.

Most fishermen have accepted the importance of *escape gaps*, and this view will be endorsed by the results of Brown's (pers. comm.) studies of the harmful effects of careless handling of undersize rock lobsters.

Recent restrictions on size of pots, and position and number of entrances, should be effective in reducing and standardising units of fishing effort.

For effective management, regulations must be planned so that enforcement becomes a practical possibility, not undermined by unnecessary difficulties. Examples of this are the choice of licensing the boat rather than the individual; avoiding if possible the enforcement of boundary lines over water — for this reason while zone boundaries have been retained, an earlier nursery closure extending to one mile from the shore was abandoned because of inspection difficulties; escape gaps, carefully selected after experiment, are easy to police, and provide complementary support to the minimum legal size which is less easy to administer.

The major management measure has been to put a limit on the number of boats and the number of pots since 1963 in an attempt to achieve optimal fishing effort. However, it has been seen that considerable increases in effective fishing effort have occurred within that framework, to the extent that effort is now well in excess of that required for MSY, and certainly for maximum economic yield (MEY), i.e. there is

overcapacity or overcapitalization in the fishery. This may to some extent be regarded as a cost of maintaining existing employment, but clearly this is an example of overshooting MSY to which limited entry systems are prone (Clark, 1980). Nevertheless the rock lobster fishery has been, and still is, regarded as highly profitable for individual fishermen, except perhaps for those who have recently acquired high interest loans to purchase boats with large license transfer costs (Bowen, 1980). Escalating fuel and labor costs will also erode profitability.

However, notwithstanding the fact of economic overfishing, the possibility of the two other important yardsticks of "growth overfishing" and "recruitment overfishing" need to be considered. Growth overfishing occurs when fishing mortality (F) is greater than the rate of fishing mortality at which the average catch per recruit is at a maximum ($F_{max.}$) (Dawson, 1980). Apart from saying that at current levels of fishing mortality the minimum legal size appears to be moderately well adjusted, the lack of precision of parameters required for an assessment of growth overfishing does not allow firm conclusions at this stage. Recruitment overfishing is defined as a situation in which the spawning stock has been reduced to a level at which the average recruitment to the stock is significantly reduced (Dawson, 1980). This has clearly not occurred, but the capacity for continued increase in fishing mortality poses the question as to whether and when the spawning stock would become sufficiently reduced to endanger recruitment. The current high catches are encouraging, but the next few years will show whether the fishery will become stabilized at these levels, or whether they are part of a system of greater catch variability consequent on a situation of instability in the fishery. Such concerns have been responsible for the increasing determination of the fishery managers to reduce the level of fishing effort which, while improving the economics of the fishery, will allow a retreat from the position of possible biological instability.

In reviewing the effectiveness of measures for management of the western rock lobster it cannot be overstressed that the proposal to introduce a limited entry system of management in 1963 was fully endorsed by individuals and groups in the fishing industry. In like manner any proposed major regulatory changes, for example, change in escape gap size or length of season, are discussed well ahead with the fishing industry, and consolidated through the Rock Lobster Industry Advisory Committee before advice is offered to the Minister for Fisheries and Wildlife. Recognizing that it is not possible to please every fisherman all of the time, the success of such cooperative arrangements is in marked contrast to similar situations which lack industry participation. The system calls for and receives scrupulously fair administration, and requires tight enforcement through effective patrol and inspection procedures.

RESEARCH AND MANAGEMENT PROBLEMS — A SUMMARY

Garrod (1979) and Parrish (1979) both draw attention to the danger of diverting scientific effort towards resource appraisal based on complex eco-system approaches — "there is a danger that it is allowed to gobble up too much of the limited research resources available, at the expense of what I call the traditional" (Parrish), and "the tendency to incorporate into advice aspects which as yet do not have a proper scientific foundation, e.g. ecosystem management." Reference to a previous section shows that research on the western rock lobster, through its

coordination by WFRC, has maintained a healthy balance, with only recently a justifiable gradation into ecosystem approaches by CSIRO, but while maintaining research on data needs for assessment for management by the State authority.

The experience of CSIRO is that rock lobster early stage larval distribution is too patchy to provide estimates which are precise enough for predictive or interpretive purposes. This understanding could only be gained by an expensive field program, based on the hard-won knowledge that vessel support must be adequate for following larvae long distances offshore.

Relationships between life history phases for which values are representative of the whole fishery have more value for predictive purposes than ones which are not. For example, studies of juvenile stages tend to produce results which are biased towards local conditions than for example total catches, "whites" (recruit) catches, indices of spawning and puerulus settlement.

The difficulty of obtaining precise enough estimates of growth, mortality and age in crustacea, even in a heavily researched fishery, remains. Until this can be overcome surplus yield assessment models, notwithstanding their deficiencies, will need to be employed for management purposes at the expense of dynamic pool models.

Limited entry management systems cannot, and do not, prevent levels of fishing effort overshooting those required for MSY or some other management objective. As Clark (1980) puts it "each licensed fisherman will be motivated to undertake any action that will increase his share of the catch." However, the option of quota levels, with or without limitation of licenses, has not yet been considered to be a practical alternative.

Figure 3 shows that assessment based on nominal effort gave a much more optimistic view than that using effective effort. Failure to base assessment on effective effort might have permitted even greater overshooting of optimum effort than that actually experienced.

Problems arise when legislative changes interrupt the sequence of data gathered for assessment models, often with consequent difficulties of standardization for annual comparisons, such as length of season or minimum legal size.

Adoption of a limited entry system must inevitably involve some controls on individual efficiency. For the western rock lobster fishery these have involved the size of vessel, number of pots, size of pots, number and position of pot entrances. Without them a serious reduction in the number of licenses would have been required to offset the increase in fishing effort beyond the optimum which has occurred even despite such constraints. As Clark (1980) summarized "while these problems, which are of course particularly typical of the open-access fishery, may be somewhat alleviated by the use of licenses, in many cases various additional regulations will be required. The length, tonnage and horsepower may need to be controlled. As vessels become more efficient, the number of licensed vessels may have to be reduced. Restrictions may have to be placed on fishing gear and on detection equipment. . . . Unless very carefully planned and administered, these measures will have a negative effect on efficiency." Such reductions in efficiency take on an even more serious aspect in current times of escalating fuel and labor costs, and must be carefully evaluated accordingly.

Transferable licenses attract a market value related to the number of pots

licensed. The price per pot has been estimated by Bowen (1980) to be about equivalent to the catch of one rock lobster pot in 1 year or the value of approximately 100 kg. Such transfer values, amounting therefore to many thousands of dollars, have added substantially to the capitalization of the fishery. The result, particularly for new entrants to the fishery with large bank loans to service, will be to generate maximum catches with associated pressure on the stocks.

A fully regulated and license limited fishery should not be contemplated without full awareness of the high cost of administration, research and particularly inspection.

ACKNOWLEDGMENTS

Special thanks are due to N.G. Hall for data processing and helpful advice, to I. Lethbridge for the figures, to J. Kennedy for word processing, and to B.K. Bowen, R.S. Brown and B.F. Phillips (also for access to unpublished information) for critically reading the manuscript.

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